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Dispersed fungal remains from the Neogene Siwalik forest of sub-Himalayan Arunachal Pradesh, India and their palaeoenvironmental indicative values

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Dispersed fungal remains from the Neogene Siwalik forest of sub-Himalayan Arunachal Pradesh, India and their palaeoenvironmental indicative values

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The fungal elements comprising 22 genera and 36 species have been recorded from the Lower Siwalik sediments (Middle Miocene-Upper Miocene) of Arunachal Pradesh, northeast India. The recovered fungal morphs are mostly amerospores, didymospores, phragmospores, dictyospores, helicospore and staurospore of Fungi Imperfecti and fruit bodies of epiphyllous fungi. The fungal assemblage indicates an overall warm humid tropical/subtropical climate. Some ecologically significant taxa like *Palaeocirrenalia*, *Mediaverrunites* and *Spegazzinites* have also been retrieved from these sediments further suggesting a mild influence of brackish water environmental condition during the time of deposition.

Key words: Fungal remains, Siwalik sediments, palaeoenvironment, Arunachal Pradesh, India

In spite of their high abundances in palynological preparations, fungal remains (such as mycelium, hyphae, fruit-bodies as well as spores) have received considerably less attention than palynomorphs. Lack of information on the ecological preferences of most of the fungal taxa has limited their applicability in palaeoecological reconstructions. Still attempts are made with these non-pollen palynomorphs (NPPs) recorded from a variety of depositional environments to reconstruct palaeoecological conditions through ages (Blackford, 1998). In most of the cases ecological indicative value of fungal morphotypes are assumed considering their stratigraphic association with certain environmental conditions or with already established ecological indicative values of known palynofossils in some other records or geographical contexts (Blackford and Innes, 2006). However, this indirect derivation of ecological preferences based on stratigraphic association may create ambiguity. To minimize this bias, modern nearest living relative (NLR) of every fossil fungal morphs should be identified, so that their ecological preferences could be utilized while reconstructing palaeoecological conditions. In this pretext an attempt has been made to utilize the ecological conditions of the NLRs of the fossil fungal taxa in reconstructing palaeoecological conditions and depositional environments of the Lower Siwalik sediments of Arunachal sub Himalaya.

The Siwalik sediments in the foothill region of Arunachal Pradesh are represented by Dafla formation (Lower Siwalik, Middle to Upper Miocene), Subansiri formation (Middle Siwalik, Pliocene) and Kimin formation (Upper Siwalik, Upper Pliocene to Lower Pleistocene) (Joshi and Chakraborty, 2001). The sites of sediment collection from the Lower Siwalik are characterised by interbanded medium to fine grained sandstone, shale and siltstone. A good number of fossil leaves and other plant fossil remains have been recorded by several authors from the all Siwalik stratigraphic sequence of Arunachal Sub Himalayan regions (Joshi and Mehrotra, 2003, 2007; Khan *et al.* 2008, 2009, 2015). In contrast very few palynological records including fungal spores are available from this region (Dutta, 1980; Dutta and Singh, 1980; Khan *et al,* 2006). Earlier, Pathak and Banerjee (1984) and Mandal *et al.* (2009) interpreted the palaeoenvironment on the basis of recovered fungal remains from the Lower Siwalik sediments, Nandi *et al.* (2003) from the Cretaceous and Tertiary sediments of Meghalaya and Kar *et al.* (2010) from the Miocene sediments of Mizoram, northeast India

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Table 1: List of fungal spores and epiphyllous fruit bodies recorded from the Lower Siwalik sediments of Arunachal Pradesh with their affinity and climatic interpretation

Taxa Record	Probable Botanical Affinity	Environment
Dicellaesporites elongatus Kumar 1990.	Fungi Imperfecti, Didymosporae	Tropical humid climate
Dicellaesporites obnixus Norris 1986.	Fungi Imperfecti, Didymosporae	
Dicellaesporites (Elsik1968) Scheffy & Dilcher 1971.	Fungi Imperfecti, Didymosporae	
Diporicellaesporites equabilis Kalgutkar 1993.	Fungi Imperfecti, Phragmosporae	
Diporicellaesporites navicularis Kalgutkar 1993.	Fungi Imperfecti, Phragmosporae	
Diporisporites Elsik 1968.	Fungi Imperfecti, Amerosporae	
Dictyosporites Felix 1894.	Fungi Imperfecti, Dictyosporae	
Dyadosporites megaporus Song Zhichen *et al*. 1999.	Fungi Imperfecti, Didymosporae	
Dyadosporites (Vander Hammen1954) Clarke 1965.		
Exesisporites Elsik1969.	Fungi Imperfecti, Amerosporae	
Foveodiporites gunniae Verma and Rawat 1963.	Fungi Imperfecti, Amerosporae	
Foveofusa Lele and Chandra 1972.	Fungi Imperfecti, Phragmosporae	
Fusiformisporites elongates Ramanujam & Rao 1978.	Fungi Imperfecti, Didymosporae	
Fusiformisporites foedus Salujha, Kindra and Rehman 1974.	Fungi Imperfecti, Didymosporae	
Fusiformisporites lineolatus Scheffy & Dilcher 1971.	Fungi Imperfecti, Didymosporae	
Fusiformisporites Rouse 1962.	Fungi Imperfecti, Didymosporae	
Fusidiporosporonites Song Zhichen *et al*.1989.	Fungi Imperfecti, Amerosporae	
Glomus Taylor, Remmy, Hass & Kerp 1995.	Zygomycetes , Endogonales	
Hypoxylonites armentroutii Elsik 1990a.	Uncertain (Xylariaceae)	
Hypoxylonites eocenicus Elsik 1990a.	Xylariaceae	
Hypoxylonites gulfensis Elsik 1990a.	Xylariaceae	
Hypoxylonites lineatus Elsik 1990a.	Uncertain (Xylariaceae)	
Hypoxylonites tennesseensis Elsik 1990a.	Uncertain (Xylariaceae)	
Hypoxylonites Elsik 1990a.	Uncertain (Xylariaceae)	
Inapertisporites perminutus Doubingere Pons 1973.	Fungi Imperfecti, Amerosporae	
Inapertisporites Vander Hammen 1994.	Fungi Imperfecti, Amerosporae	
Mediaverrunites (Jarzen & Elsik 1986) Nandi & Sinha 2007.	Fungi Imperfecti, Amerosporae	Tropical , Humid with brackish water environment
Multicellaesporites (Elsik 1968) Scheffy and Dilcher 1971.	Fungi Imperfecti, Phragmospore	Tropical humid climate
Microthyriaceous fruit body	Microthyriaceae	Warm (Tropical-subtropical) and humid climate
Microthyriaceous germling	Microthyriaceae	
Notothyrites Cookson 1947.	Microthyriaceae	
Palaeocirrenalia Ramanujam & Srisailam 1980.	*Cirrenalia*, Fungi Imperfecti, Helicosporae	Tropical , Humid with brackish water environment
Papulosporonites Schmiedeknecht & Schwab 1964.	Fungi Imperfecti, Dictyosporae	Tropical humid

(*Contd. Part Table* 1)

Phragmothyrites (Edwards 1972) Kar & Saxena.1976.	Microthyriaceae	Warm (Tropical-subtropical) and humid climate
Pluricellaesporites dentatus Trivedi & Verma 1970.	Fungi Imperfecti, Phragmospore	Tropical humid
Pluricellaesporites lagenosus SongZhichen *et al*.1999.	Fungi Imperfecti, Phragmospore	
Pluricellaesporites sacciformis Pearson & Norris 1999.	Fungi Imperfecti, Phragmospore	
Pluricellaesporites Vander Hammen 1994.	Fungi Imperfecti, Phragmospore	
Spegazzinites Felix 1894.	Fungi Imperfecti, Staurosporae	Tropical, Humid with brackish water environment

and Das *et al.* (2007) from the Upper Siwalik sediments of Arunachal Pradesh. Recently, Ghosh *et al.* (2017) recovered diverse fungal remains in the surface samples of tropical-sub-alpine vegetation zones of the Darjeeling Himalaya and proved the efficiency of the fungal spores in tracing the vegetation changes and grazing activities. Here we report a good number of fungal spores and fruit bodies recovered for the first time from the Lower Siwalik sediments of Arunachal sub Himalaya which can be taken into account for consideration of past environment reconstruction. The studied materials were collected from road cutting sections of south and east Pinjoli area of West Kameng District (lying between 26^{0}54´N to 28^{0}01´N and 91^{0}31´E to 92^{0}40´E) of Arunachal Pradesh. The outcrop materials investigated consist of dark, carbonaceous shales containing well preserved angiospermic leaf impressions and compressions. The palynomorphs are recovered from the samples by following conventional technique of maceration (Batten, 1999) using HCL (10%), HF (40%), HNO3 and KOH (5%).

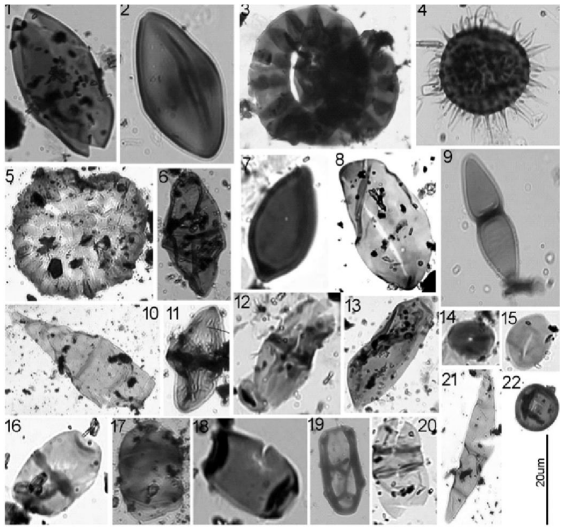

Fig. 1 : Some significant fungal remains: 1. *Hypoxylonites armentroutii,* 2. *Mediaverrunites* sp., 3. *Palaeocirrenalia* sp., 4. *Spegazzinites* sp., 5. *Phragmothyrites* sp., 6. *Dicellaesporites elongates*, 7,18. *Diporisporites* sp., 8. *Hypoxylonites lineatus,* 9. *Dyadosporites* sp., 10. *Pluricellaesporites sacciformis,* 11. *Fusiformisporites foedus,* 12. *Fusiformisporites* sp., 13. *Foveofusa* sp., 14. *Exesisporites* sp., 15. *Hypoxylonites* sp., 16. *Dyadosporites megaporus,* 17. *Pluricellaesporites lagenosus,* 19. *Dictyosporites* sp., 20. *Pluricellaesporites dentatus*, 21. *Diporicellaesporites navicularis*, 22. *Inapertisporites* sp.

The fungal spores and fruit bodies are common in the studied samples and they contribute more than 35% to the total assemblage of the palynomorphs. In the fungal assemblage didymospore is present in highest percentage (23.68%) followed by phragmospore (21.06%), and amerospore (18.42%) while dictyospore, staurospore and helicospore represented almost uniformly (3.54% each). The spores of Xylariceae were recovered in 15.7% and that of microthyriaceous fruitbody 10.52% (Fig. 1). Their probable modern relatives are shown in Table 1.

Out of 36 species under 22 genera of recovered fungal remains, 20 genera belong to dispersed spores and 2 genera to the microthyriaceous ascostromata. Diverse and rich fungal remains in the assemblage reflect the presence of luxuriant vegetation with plenty of wood logs, litters and other decaying organic remains in the floor of the Siwalik forest. Richness of spores in the sediment indicates tropical humid climatic condition with high rate of precipitation. Earlier, Khan *et al.* 2014 quantified the climatic parameters on the basis of CLAMP (Climate Leaf Analysis Multivariate Program) analysis

of angiosperm fossil leaves from the Lower Siwalik sediments of Arunachal Pradesh and suggested a warm humid tropical climate with distinctive monsoonal signature prevailed during the middle to upper Miocene. As per the CLAMP quantification, the mean annual temperature (MAT) was 25.29 ºC. Although the precipitation estimates had high uncertainties but suggested a monsoon with growing season precipitation (GSP) of 174.13 cm and mean monthly growing season precipitation (MMGSP) of 19.97cm. Similarly, the rich fungal remains from the studied sediments provide an authentic evidence of coupled high temperature – precipitation condition which might be responsible for this luxuriant growth of the fungal taxa. Recovery of a good number of well preserved fossil leaf impressions (Joshi and Mehrotra, 2003, 2007; Khan *et al.* 2008, 2009) belonging to tropical to subtropical semi evergreen and deciduous broad-leaved forests from the same fossiliferous beds also corroborate the prevailing humid climate in the region during Middle to Upper Miocene sedimentation. Fossil ascospores of Xylariaceae (*Hypoxylonites* spp.) in the assemblage suggest prevalence of terrestrial woody angiosperms in the tropical humid and swampy environmental ecosystem. Most of the modern members of the Xylariaceae grow on rotten woods or as parasite on some angiosperms (Elsik, 1990).

Spores of some ecologically significant taxa like *Palaeocirrenalia*, *Mediaverrunites* and *Spegazzinites* have also been retrieved from the studied sediments. The genus *Palaeocirrenalia* resembling modern *Cirrenalia* indicates influence of brackish water in the depositional area (Ellis, 1976; Rao, 1995). Occurrence of *Mediaverrunites* in the sedimentsusually indicates a warm tropical deltaic setting during the time of deposition (Jarzen and Elsik, 1986; Nandi and Sinha, 2007; More *et al*. 2016). However, Schutz and Shumilovskikh (2013) described its modern counterpart i.e. *Potamomyces armatisporus* as a pantropical lignicolous fresh water fungus occupying terrestrial habitats in tropical and subtropical regions. Hence, presence of *Mediaverrunites* is also indicative of a broad-leaved forest, might be in deltaic setting. Recovery of the genus *Spegazzinites* further supports the influence of mild brackish water condition in the depositional area (Guimares *et al.* 2013). Its modern representative *Spegazzina* is a common element of the tropical humid regions with brackish water influence (Ramanujam and Srisailam, 1980).

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